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Original Research

A comparison of factors influencing ACL injury in male and female athletes and non-athletes

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Abstract

Objectives: The purpose of this study was to compare knee joint laxity and muscular strength between male and female athletes and male and female non-athletes, and to determine if any differences existed among these variables.
Participants: Fifty-four (27 male, 27 female) apparently healthy athletes and fifty-three (25 male, 28 female) non-athletes volunteered.
Main outcome measures: The KT-1000 knee arthrometer quantified knee joint laxity during three passive drawer tests (66, 89, and 133 N); one active drawer test; and one maximum manual displacement test. The Biodex isokinetic dynamometer measured muscular strength during five maximal repetitions at 60°/s.
Results: Non-athletes had significantly greater laxity compared to athletes on three of the variables. No significant differences were found between males and females in laxity. Athletes had significantly greater peak torque of the quadriceps and hamstring muscles as well as a greater hamstring to quadriceps (*H*:*Q*) ratio compared to non-athletes. Males produced significantly greater peak torque of the quadriceps and hamstrings compared to females.
Conclusions: These findings suggest that laxity is related more to athletic participation than gender; therefore, knee joint laxity may not explain the higher incidence of anterior cruciate ligament (ACL) injury in females. However, gender differences in peak torque suggest that strength may influence the higher knee injury incidence in female athletes.

Keywords: ACL; Laxity; *H*:*Q* ratio

1. Background

Female participation in intercollegiate athletics is rising. Studies completed by the National Collegiate Athletics Association (NCAA) from 1989 to 1992, found a 9% increase in female athletes in all NCAA athletic programs (Arendt & Dick, 1995). A 1990–1993 injury survey of approximately 15% of NCAA member institutions reported an average knee injury rate of greater than one injury for every 10 females. At the collegiate level during any given year, more than 10,000 knee injuries are expected to occur in female athletes, including more than 2200 ACL ruptures in female collegiate athletes (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). A study done by Engstrom, Johansson, and Tornkvist (1991) reported that athletes lost 74 days of training after an acute ACL rupture of the knee, with 239 days of absence from training after ACL reconstruction.

Several researchers have demonstrated that female athletes are at a higher risk of sustaining an ACL injury compared to their male counterparts (Arendt & Dick, 1995; Hutchinson & Ireland, 1995; Moeller & Lamb,

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1997). More specifically, research has found the sports of soccer and basketball to have a disproportionately higher number of ACL injuries in female collegiate athletes compared to male collegiate athletes. Arendt and Dick (1995) found that female soccer players had an ACL injury rate at least twice as high as male soccer players. Statistics compiled from 1990 to 1993 found that female basketball athletes had ACL injuries 3.83 times the rate of male basketball athletes, while female soccer players had an injury rate of 2.38 times that of their male counterparts. The NCAA injury surveillance system database was reviewed from 1990 to 2002 for ACL injuries in both men and women basketball and soccer players. Of all the schools sponsoring these sports, 15.6% participated in the project. In basketball, a total of 628 ACL injuries occurred (514 women, 168 men) and 586 ACL injuries occurred in soccer (394 women, 192 men) (Agel, Arendt, & Bershadsky, 2005). When compared to the previous research reported by Arendt and Dick (1995), the rate of ACL injuries in basketball remained stable for both men and women over the 13 years. In soccer, the rate of ACL injuries remained constant for females; however, the rate significantly ($p = 0.02$) decreased for male players (Agel et al., 2005).

Arendt and Dick (1995) reported that 78% of ACL injuries are through non-contact movements. However, the increased risk of injury among women is likely multifactorial. Both extrinsic and intrinsic factors have been identified as possible ACL risk factors. Knee joint laxity has been suggested as one of the possible risk factors predisposing female athletes to a greater risk of ACL injury. However, research results have not been consistent. Female collegiate athletes displayed greater knee joint laxity compared to males during the application of a 133 N anterior displacement force (Huston & Wojtys, 1996; Rozzi, Lephart, Gear, & Fu, 1999). Other authors have reported no gender differences in knee joint laxity in high school athletes during passive displacement (Weesner, Albohm, & Ritter, 1986) and the Lachman maximum test (Anderson, Snyder, Federspiel, & Lipscomb, 1992). In another study investigating male and female collegiate soccer athletes and non-athletes, no significant gender differences were reported during passive and active displacement test; however, during the Lachman maximum test, females displayed significantly ($p = 0.006$) greater maximum knee joint laxity compared to males (Medrano & Smith, 2003). Medrano also reported that athletes had significantly less laxity compared to non-athletes.

Some authors have investigated the effect of fatigue on laxity. Wojtys, Wylie, and Huston (1996) examined healthy non-athletes and reported that after muscle fatiguing exercises, both males and females displayed an increase in anterior tibial translation at 133 N. Skinner, Wyatt, Stones, Hodgdon, and Barrack (1986) found similar results when comparing laxity on the left knee but no significant difference was found on the right knee despite exposure to extra fatiguing exercises. Rozzi, Lephart, and Fu (1999) found that isokinetically induced muscular fatigue did not affect anterior tibial translation in male and female collegiate basketball and soccer players.

Athleticism has been found to affect knee joint laxity. Male and female non-athletes have been found to have greater knee joint laxity than male and female athletes (Huston & Wojtys, 1996; Medrano & Smith, 2003). Huston and Wojtys (1996) found that female non-athletes produced the greatest anterior tibial translation followed by male non-athletes, female athletes, and male athletes. Some researchers have suggested that strength, conditioning and muscle recruitment rather than knee joint laxity may be a predisposing factor for increased ACL injury rates in female basketball players (Weesner et al., 1986) and collegiate soccer players (Medrano & Smith, 2003).

A muscular strength deficit has been linked with an increased risk of knee injury (Devan, Pescatello, & Faghrit, 2004; Huston & Wojtys, 1996; Moeller & Lamb, 1997). A low hamstring to quadriceps (H:Q) strength ratio has been suggested to be a contributing factor to the increased number of ACL ligament tears (Huston & Wojtys, 1996). Additionally, Baratta et al. (1988) found a reduced coactivation pattern of the unexercised antagonist muscle to the hypertrophied agonist muscle increased the risk of ligamentous damage.

The presence of an H:Q strength ratio below normal range was linked to an increased incidence of overuse knee injuries among female collegiate athletes (Devan et al., 2004). Although the normative values used were not specific to an athletic population, H:Q strength ratios were divided into two categories: above normal Biodex range ($>69\%$ at 60°/s and $>95\%$ at 300°/s) and below normal Biodex ranges ($<60\%$ at 60°/s and $<80\%$ at 300°/s). Another study reported that if hamstring muscles had less than 75% the strength of the quadriceps muscles at 180°/s, athletes were 1.6 times more likely to get injured compared to those who had stronger hamstrings in relation to their quadriceps (Knapik, Bauman, Jones, Harris, & Vaughan, 1991).

Male high school basketball players and collegiate athletes produced more peak torque, work, and average power compared to their female counterparts (Anderson, Dome, Gautam, Awh, & Rennirt, 2001; Huston & Wojtys, 1996). Males also demonstrated significantly higher ($p<0.04$) H:Q strength ratios at 60°/s compared to females (Anderson et al., 2001). Although females have demonstrated decreased H:Q strength ratios, Moeller and Lamb (1997) reported that a decreased H:Q strength ratio was not linked as a cause of ACL injuries in women. Other research has found no gender difference in muscular strength when normalized to body weight (Wojtys et al., 1996). Additionally, no differences have been found in the H:Q strength ratios between athletes in different sports (Rosene, Fogarty, & Mahaffey, 2001) or among different divisions of basketball and soccer players at 60°/s and 180°/s (Zakas, Mandroukas, Vamvakoudis, Christoulas, & Aggelopoulou, 1995).

2. Purpose

The purpose of this study was to investigate variables that have been identified as potential ACL risk factors (knee joint laxity and muscular strength) to determine whether any differences exist among male and female athletes and non-athletes. Prior to data collection, the research was approved by the University Institutional Review Board and all volunteers provided written consent to participate.

3. Methods

3.1. Participants

Fifty-four apparently healthy athletes (27 male, 27 female) were recruited from the intercollegiate athletic department (soccer, football, softball, volleyball, basketball, tennis, track), and 53 age-matched (18–25 years) non-athletes were recruited from the general student body (25 male, 28 female). Participants had no history of knee joint ligament injury to their dominant knee, and refrained from physical activity 3 h prior to testing.

3.2. Materials and procedures

Basic descriptive characteristics (Table 1) were documented for each participant by self-report using a brief survey that included questions regarding age, gender, athletic status, lower extremity injury and leg dominance. Leg dominance was determined by asking the participants which leg they would use to kick a soccer ball. Following the completion of the survey and the measurement of each participant's height and weight by standard methods, knee joint laxity and muscular strength were determined. The same researcher performed all measurements.

3.2.1. Knee joint laxity test

The KT-1000 knee arthrometer (MEDMetric Corporation, San Diego, CA) was used to quantify knee joint laxity by measuring anterior tibial translation. The KT-1000 was selected because it was shown to generate the highest diagnostic accuracy for measuring anterior laxity, when compared to other measurement systems (Anderson et al., 1992). All displacement measurements were taken from the dominant leg only (Fagenbaum & Darling, 2003; Hagood, Solomonow, Baratta, Zhou, & D'Ambrosia, 1990; Rozzi, Lephart, Fu, 1999; Rozzi, Lephart, Gear, et al., 1999).

Participants were placed in a supine position with their legs resting on a support at 30° knee flexion. The KT-1000 knee arthrometer was placed onto the anterior aspect of the tibia of the dominant knee and secured to the lower leg above the medial and lateral malleolus by Velcro® straps (Figs. 1 and 2). Knee joint laxity was indicated in millimeters by a displacement dial on the KT-1000. The displacement dial was zeroed before each laxity trial.

Five measurements of anterior tibial translation were recorded from each participant: passive drawer tests at three displacement loads, an active drawer test, and a maximum manual displacement test. The passive drawer test of tibial translation was performed by obtaining three measurements at each displacement load of 66, 89, and 133 N. The anterior tibial translation value recorded for each displacement load was defined as the mean value of the three measurement trails.

The active drawer test was measured once to determine the effect of quadriceps contraction on anterior tibial translation. With the arthrometer still attached to the leg, the participants were asked to contract their quadriceps and slowly lift their heel off the table. The measurement was taken from the dial when the needle ceased to move, thus indicating the end point of anterior tibial translation (Medrano & Smith, 2003).

Table 1
Mean (SD) characteristics of all participants

	Females		Males	
	Non-athletes	Athletes	Non-athletes	Athletes
Age (years)	19.30 (1.46)	22.11 (1.69)	21.45 (1.26)	22.04 (2.07)
Weight (kg)	65.62 (7.80)	62.63 (10.79)	92.58 (20.12)	82.60 (13.90)
Height (cm)	169.89 (5.80)	162.73 (6.09)	183.83 (9.42)	177.20 (6.25)

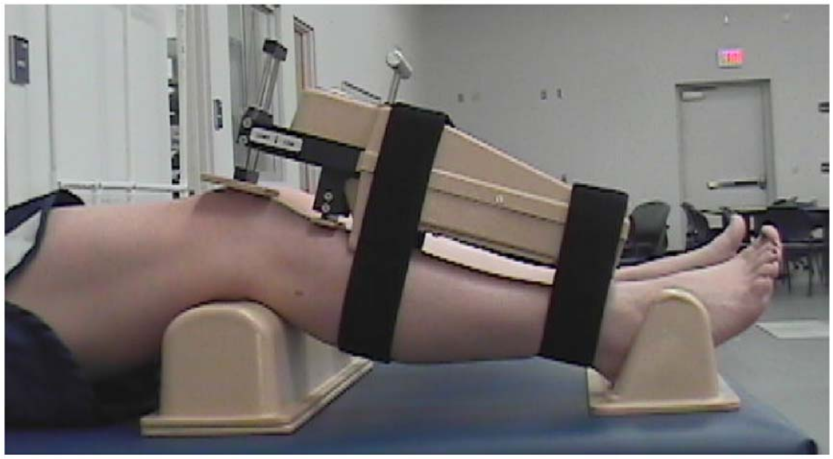

Fig. 1. KT-1000 knee arthrometer secured to the lower leg.

Fig. 2. Subject in supine position during laxity test.

With the KT-1000 still attached to the leg, a maximum manual drawer test was performed once in which the examiner applied maximum anterior force to the proximal aspect of the calf while maintaining control of the patella pad of the KT-1000. A maximum value was recorded from the displacement dial of the arthrometer when the examiner could no longer move the leg in an anterior direction.

Upon completion of laxity testing, each participant proceeded with a 4-min warm-up on a stationary bike at a comfortable workload. A standardized sequence of stretching (10-min led by the researcher) was performed before isokinetic testing.

3.2.2. Muscle strength test

Peak torque and time to peak torque of the hamstring and quadriceps muscles, and the concentric hamstring to quadriceps (H:Q) strength ratio were measured using the Biodex Isokinetic Dynamometer (Medical Systems Inc., Shirley, NY) at 60°/s.

Each participant was secured to the chair of the Biodex machine by nylon straps placed across the shoulders and chest, the hips, and the thigh and ankle of the dominant leg. The seatback tilt was set at 85°. The dynamometer's lever arm was strapped to the lower leg just above the ankle joint. The axis of rotation of the dynamometer was aligned midway between the lateral condyle of the tibia and the lateral epicondyle of the femur which is consistent with the anatomical axis of the knee joint (Fig. 3). The weight of the participants' leg, including the lever arm, was measured and a correction for the effect of gravity was applied by the computer's software (Gleeson, Reilly, Mercer, Rakowski, & Rees, 1998). Failure to correct for the effect of gravity could have resulted in an overestimation of the *H*:*Q* ratio which then could give a perceived increase in the strength of the hamstring relative to the quadriceps (Rosene et al., 2001). Range of motion was set just short of maximal extension and maximal flexion for each individual participant.

Fig. 3. Biodex isokinetic machine.

Table 2
Mean (SD) from knee joint laxity tests

	Female		Male	
	Non-athlete	Athlete	Non-athlete	Athlete
PD 66 N (mm)	2.7 (0.99)	2.3 (0.81)	2.8 (0.86)	2.4 (0.78)
PD 89 N (mm)	3.6 (1.17)	3.1 (1.20)	3.7 (1.28)	3.1 (1.14)
PD 133 N (mm)	4.7 (1.60)	4.2 (1.49)	4.8 (1.87)	4.0 (1.37)
Active (mm)	5.3 (2.24)	4.4 (1.42)	5.4 (2.20)	4.4 (1.69)
Maximum (mm)	6.1 (2.30)	6.0 (2.05)	6.4 (2.72)	4.9 (2.24)

Note: PD 66 N, PD 89 N, and PD 133 N represent passive displacement at loads of 66, 89, and 133 N, respectively. Active represents the active displacement test.

Participants performed 2–4 sub-maximal warm-up contractions. Five maximal voluntary contractions at an angular velocity of 60°/s were performed. The same verbal encouragement was provided to all participants. Peak torque of the hamstring and quadriceps muscles, time to peak torque of the hamstring and quadriceps muscles, and the concentric hamstring to quadriceps (*H*:*Q*) strength ratio were measured and recorded.

4. Main outcome measures

4.1. Statistical analysis

This prospective, factorial design had two independent variables (gender, athletic status) with two levels each (male/female, athlete/non-athlete) that were tested using a multivariate analysis of variance (MANOVA). The statistical analyses were run using the statistical analysis system (SAS, V9.1.3). Alpha was set at the 0.05 level of significance for all statistical tests.

5. Results

The mean (SD) of each knee joint laxity variable and muscular strength variable are presented in Tables 2 and 3, respectively. Using the Wilks' λ statistic, the MANOVA revealed an overall significant effect for athletic status ($p = 0.0038$) and an overall significant gender effect ($p < 0.0001$). None of the athlete status∗gender interactions were significant, therefore the univariate main effects were evaluated. For each of the variables, the Shapiro–Wilk statistic for normality indicated the data were normally distributed ($p > 0.05$).

5.1. Knee joint laxity

Athletes had significantly less knee joint laxity during passive displacement at 89 N ($p = 0.0214$) and 133 N ($p = 0.0484$), and during active displacement ($p = 0.0171$) compared to non-athletes (Fig. 4). No significant differences were found between athletes and

Table 3
Means (SD) from muscular strength tests

	Female		Male	
	Non-athlete	Athlete	Non-athlete	Athlete
Peak torque quadriceps (Nm)	137.22 (30.84)	167.55 (28.75)	232.57 (47.99)	253.14 (64.97)
Peak torque hamstring (Nm)	63.74 (14.67)	86.90 (14.09)	113.24 (28.86)	131.81 (39.70)
Time to peak torque quadriceps (ms)	503.57 (123.63)	522.96 (102.46)	476.40 (134.19)	475.93 (133.83)
Time to peak torque hamstring (ms)	540.71 (177.76)	556.30 (139.65)	539.60 (176.36)	519.26 (183.78)
Hamstring/quadriceps ratio (%)	46.79 (6.00)	52.40 (7.30)	48.86 (6.39)	52.01 (8.51)

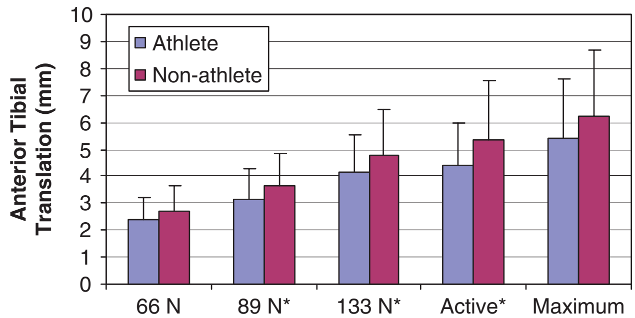

Fig. 4. Mean (SD) knee joint laxity between athletes and non-athletes. *Note*: * represents significance ($p<0.05$).

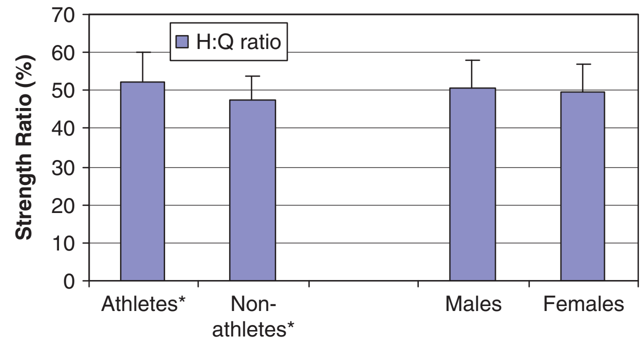

Fig. 6. Mean (SD) H:Q strength ratio. *Note*: * represents significance ($p<0.05$).

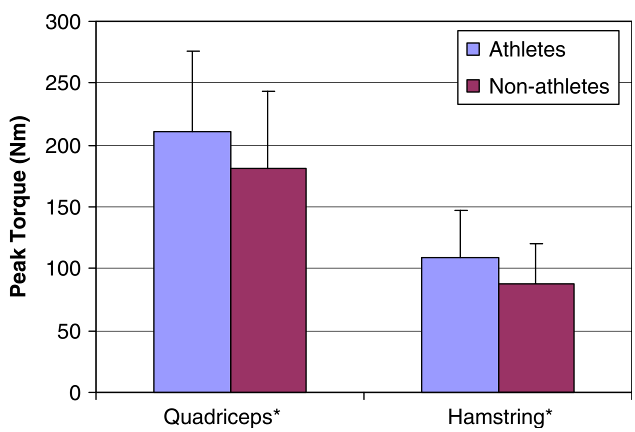

Fig. 5. Mean (SD) quadriceps and hamstring peak torque between athletes and non-athletes. *Note*: * represents significance ($p<0.05$).

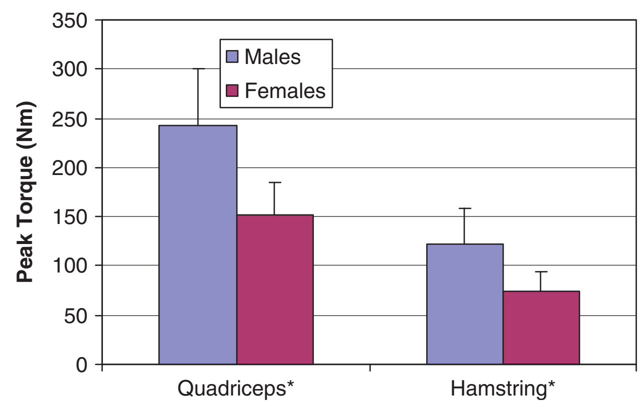

Fig. 7. Mean (SD) quadriceps and hamstring peak torque between males and females. *Note*: * represents significance ($p<0.05$).

non-athletes on passive displacement at 66 N ($p=0.05$) or the maximum manual test ($p=0.08$). No significant gender differences were found for any knee joint laxity variable.

5.2. Muscle strength

Athletes were significantly stronger than non-athletes for quadriceps peak torque ($p=0.0040$), hamstring peak torque ($p<0.0001$), and the H:Q strength ratio ($p=0.0019$) (Figs. 5 and 6, respectively). Males were significantly stronger than females for quadriceps peak torque ($p<0.0001$) and hamstring peak torque ($p<0.0001$) (Fig. 7). No significant differences were found between athletes and non-athletes on time to peak torque for the quadriceps ($p=0.69$) or time to peak torque for the hamstrings ($p=0.94$). No significant gender differences were found on time to peak torque for the quadriceps ($p=0.13$), time to peak torque for the hamstrings ($p=0.56$), and the H:Q strength ratio ($p=0.55$).

6. Discussion

This study investigated knee joint laxity and muscular strength to determine if any differences existed between male and female athletes and non-athletes. The results of this study revealed that non-athletes had significantly more laxity than athletes during passive displacement loads of 89 and 133 N, and the active displacement test which supports previous research by Medrano and Smith (2003) and Weesner et al. (1986). Medrano and Smith (2003) reported non-athletes had greater laxity in passive, active, and maximum manual displacement than athletes, but it was also reported that there were no differences between males and females in the passive and active drawer test, except during the maximum test, where females displayed significantly greater laxity than males. In the current study, no significant differences were found in any laxity measurements between males and females. This failed to support other reports (Huston & Wojtys, 1996; Rozzi, Lephart, Gear, et al., 1999) that found significant differences in knee joint laxity between genders.

The muscular strength data revealed that athletes produced significantly more peak torque in both the quadriceps and hamstring muscles compared to non-athletes along with a significantly higher $H{:}Q$ ratio. These data also revealed that males produced significantly more peak torque of the hamstring and quadriceps muscles compared to females.

During sport activities, such as soccer or basketball, an athlete's knee may endure forces that exceed five times their body weight. Ligaments alone cannot stabilize the knee under these increased loads, therefore, the surrounding muscles help protect the knee joint, allowing the knee to tolerate greater stress and strain (Huston & Wojtys, 1996). The quadriceps muscle can contribute to the excess forces required to cause ACL failure. Contraction of the hamstring muscles can counteract the force created by the quadriceps and help control anterior tibial translation (Anderson et al., 2001). A balance between the quadriceps and hamstring muscles is important for normal knee function and for reduction in the risk of knee injuries. In response to anterior tibial translation, female athletes have been shown to rely more on the quadriceps and gastrocnemius for initial knee stabilization, while male athletes recruited the hamstrings (Huston & Wojtys, 1996). Women have also been noted to land with greater knee extension compared to men (Cowling & Steele, 2001; Decker, Torry, Wyland, Sterett, & Steadman, 2003; Huston, Vibert, Ashton-Miller, & Wojtys, 2001). Hamstring muscle activation can reduce ACL strain, but the co-contraction of the hamstring and quadriceps muscles cannot reduce ACL strain near full extension (Huston et al., 2001), therefore, landing with a straighter knee may increase ACL strain and the risk of injury.

Researchers have found that athletes who did not exercise their hamstrings have substantially decreased hamstring coactivation patterns compared to athletes who regularly exercised their hamstrings (Baratta et al., 1988). Unopposed quadriceps contractions could translate the tibia anteriorly and cause significant strain in the ACL (Huston & Wojtys, 1996). Coactivation of the quadriceps and hamstrings is essential for maintaining knee stability and is believed to eliminate the primary rotary laxity of the knee (Baratta et al., 1988; Hagood et al., 1990). Strength training can improve the contribution of the hamstring musculature and provide more protection to the knee joint (Hagood et al., 1990).

A muscular strength imbalance between the quadriceps and hamstring muscles is another possible mechanism to explain ACL injury in athletes (Rosene et al., 2001). In the current investigation, the $H{:}Q$ ratio was not significantly different ($p = 0.55$) between genders, but the $H{:}Q$ ratio was significantly ($p = 0.0019$) higher for athletes (52.21%) compared to non-athletes (47.77%). Rosene et al. (2001) reported no differences in the $H{:}Q$ strength ratio between athletes in different sports and Zakas et al. (1995) found no difference between athletes of different divisions. Both authors attributed the findings to training adaptations by the participants for their respective sports, game demands and level of competition.

Athletes in the current study were all competing in Division I athletics and underwent similar training routines at similar intensity levels. The participants were involved in sports that require similar movements of running and jumping. This may partially explain why the $H{:}Q$ ratios of the male and female athletes were very similar and support both Rosene et al. (2001) and Zakas et al. (1995). It was expected that athletes generally have higher muscular strength and endurance compared to non-athletes. In the current study, the amount of physical activity and strength and conditioning for each non-athlete was not recorded. It cannot be determined how fit each non-athlete was at the time of testing, but one can assume that if the non-athletes did engage in physical activity, the intensity and total volume of their training was not likely to have been equal to that of the athletes.

According to Devan et al. (2004), an $H{:}Q$ ratio above normal Biodex range is $>69\%$ at 60°/s and $>95\%$ at 300°/s and below normal Biodex range is $<60\%$ at 60°/s and $<80\%$ at 300°/s. In the current study, participants fell well below this normative standard and athletes revealed an average $H{:}Q$ ratio of 52.21%. Of the 54 athletes, only 10 athletes (six males, four females) demonstrated an $H{:}Q$ ratio greater than 60%. There were no non-athletes who had an $H{:}Q$ ratio greater than 60%. Several studies have documented that muscular strength deficits and low $H{:}Q$ ratios are linked to injury (Devan et al., 2004; Fried & Lloyd, 1992; Hutchinson & Ireland, 1995; Knapik et al., 1991; Rosene et al., 2001; Soderman, Alfredson, Pietila, & Werner, 2001). It has been reported that the normal $H{:}Q$ ratio is considered to be 50–80% (Rosene et al., 2001). Although athletes in the current study had a greater $H{:}Q$ ratio than non-athletes, these athletes scored below the recommended minimums (Devan et al., 2004) and may be at risk for injury.

7. Conclusions

Non-athletes displayed greater laxity than athletes, but no gender differences were found in any of the laxity measurements. These findings suggest that laxity is related more to athletic participation than gender; therefore, knee joint laxity may not explain the higher incidence of ACL injury in females. However, gender differences in peak torque suggest that strength deficit should be investigated as a possible risk factor explaining the higher knee injury incidence in female athletes compared to male athletes. Even though males were found to be stronger than females, a gender difference in the *H*:*Q* ratio was not revealed. This suggested that females are proportionately weaker than males in both the quadriceps and hamstrings and that a lower *H*:*Q* ratio may be linked to athletic participation rather than gender. However, both athletes and non-athletes in this study were well below the recommended concentric *H*:*Q* strength ratio. Coaches, athletes, trainers, and therapists should focus on improving the *H*:*Q* ratio to reduce the risk of injury to both males and females.

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